

The Sight Distance Issues with Retrofitted Single-Lane HOV Facilities

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ABSTRACT

It is well-known that obstruction inside a highway horizontal curve will lead to impaired sight distance. Highway alignment design standards in terms of the minimum horizontal curve radius are specified to allow for adequate stopping sight distance at given design speeds. For a single-lane HOV facility, inside curve obstruction may occur no matter when the facility curves to the left (per travel direction) or right. A unique situation that calls for special attention is that the adjacent mixed-flow lane traffic, once queued, may become sight obstruction. Calculations indicated that such obstruction may govern the minimum curve radius design as long as the left shoulder is not less than 0.92 m, when the HOV lane is contiguous to the mixed-flow lanes. Such governance may necessitate design speed reduction, horizontal and cross-section design adjustment, or both.

1. INTRODUCTION

A High Occupancy Vehicle (HOV) lane is a dedicated facility for high occupancy vehicles. A HOV lane moves more people with fewer vehicles by requiring the minimum passenger occupancy level. For example, a typical occupancy requirement is two or more persons per vehicle. HOV lanes are well recognized as an effective congestion mitigation strategy. As of 2008, HOV facilities are operating in more than 34 metropolitan areas in North America [1].

Installation of a HOV lane can be accomplished through ‘take-a-lane’ or ‘add-a-lane’ strategies. ‘Take-a-lane’ means to designate one of the existing mixed-flow lanes for HOV purpose only; while ‘add-a-lane’ means to widen the existing facility and increase one additional lane for high occupancy vehicles. Certainly ‘take-a-lane’ would be easier to implement, but it may also lead to public complaints due to the reduced capacity in the remaining mixed-flow lanes. ‘Add-a-lane’ strategy is therefore preferred in practice.

Due to the possible financial, environmental, and right-of-way constraints, HOV lanes are typically retrofitted along the median of existing freeway facilities as single-lane facilities. On the left side (per travel direction), a single-lane HOV facility is installed right next to the median barrier with or without standard shoulder width. On the right side, the single-lane facility may be physically separated from the adjacent mixed-flow lanes either by a concrete barrier, or by a buffer area demarcated by pavement markings as shown in Figure 1. The buffer area may be as wide as a full lane, or as narrow as zero, so that the HOV lane becomes contiguous with the mixed flow lanes as shown in Figure 2. A physically separated HOV facility allows for access (in and out of the facility) only at designated access points; while a contiguous HOV facility allows for access at any point along the facility.



Figure 1. Buffer-Separated HOV lanes with tall median barrier.

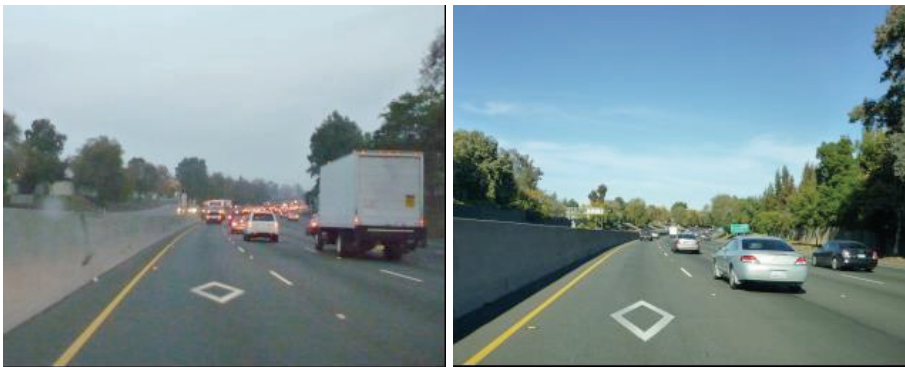


Figure 2. A HOV lane contiguous with mixed-flow lanes.

For multilane highway facilities, only the median and edge lanes suffer the most from inside-curve obstruction. Therefore, only the median and edge lanes necessitate the adequacy check of stopping sight distances. For a single-lane HOV facility, the HOV lane becomes both the median and the edge lane, and thus it may suffer from inside-curve obstruction whenever the facility curves, be it to the left, or to the right. Therefore, the HOV lane must be checked for the adequacy of stopping sight distances whenever the facility curves.

On the left-hand-side, the inside curve sight obstruction may come from median barriers, bridge piers, or median plantings. On the right-hand-side, the frequent inside curve sight obstruction may come from the queued traffic in the adjacent mixed flow lanes. As typical part-time facilities, HOV lanes operate in a designated time-of-day during the morning and/or evening peak period. The designated operation periods correspond with the congested periods of the adjacent mixed-flow lanes. Indeed, the basic rationale to install HOV facilities is to provide the high occupancy vehicles with higher level of service when the mixed-flow lanes become congested. Observation indicated that the HOV lane traffic may operate at speeds 30 kph higher than its mixed-flow counterparts [2].

In this paper, the unique situation that a single-lane HOV facility suffers from is first pointed out, that is the possible inside curve obstruction by queued traffic in the mixed-flow lanes when the facility curves to the right. Calculations are then performed to identify and evaluate when such inside curve obstruction may govern the geometric design. Countermeasures are finally recommended to mitigate the situation either by reducing design speed, by altering horizontal and cross-sectional design, or by both. Note that the discussions are limited to horizontal alignment only.

2. SIGHT DISTANCE DEFINITIONS AND CALCULATIONS

2.1 Sight Distance Definitions

Sight distance refers to the length of roadway that is visible to the driver. As the minimum sight distance, stopping sight distance must be provided on 100% of the roadway system so that a driver with standard eye height can see an object of standard height with sufficient time to stop safely [3]. According to the AASHTO Green Book [4], the standard eye height is 1070 mm; while the standard object height is 150 mm.

Stopping sight distance is an essential design element. Stopping sight distance calculation involves virtually all elements of highway design and many elements of highway operations and control. As Lytton [3] pointed out, the following seven design variables are essential in determining the stopping sight distance:

- Perception-reaction time
- Driver eye height
- Object height
- Vehicle operating speed
- Pavement coefficient of friction
- Deceleration rates
- Roadway design

Sight distance has a significant influence on roadway safety. Studies indicated that locations with stopping sight distance that is less than the AASHTO policy minimum stopping sight distance were found to have an average of about 40% more accidents than nearby locations with adequate sight distance [5]. Every effort should be made to ensure adequate stopping sight distance in HOV facility design. In this paper, the discussions are limited to perception-reaction time, vehicle operating speed, and roadway design. The rest of the variables follow the typical design values recommended by the AASHTO green book [4]. For example, the typical deceleration rate is 3.4 m/s^2 , besides the typical driver eye height and object height mentioned above.

2.2 Sight Distance Calculations

Per the AASHTO Highway Geometric Design Policy [4], the minimum sight distance necessary for a driver to safely stop before a downstream obstruction can be calculated as follows:

$$SSD_d = \frac{v}{3.6} \cdot t + \frac{v^2}{25.92 \cdot a} \quad (1)$$

Where, SSD_d = The necessary SSD for a given design speed, v , m; a = Deceleration rate of 3.4 m/s^2 ; SSD = Sight distance, m, v = Design speed for SSD computation, kilometer per hour (kph); t = Perception-reaction time, and is set at 2.5 s according to the AASHTO Green Book [4]. For example, when $v = 80$, and 110 km/h, the SSD is determined as 128.2, and 213.7 m, respectively.

For a horizontal curve segment, the available SSD is determined by the curve radius and ordinate offset. The ordinate offset is also called the middle ordinate, which is the distance from the center of the inside lane to the obstruction. The allowable SSD at a curved segment can be calculated as:

$$SSD_s = \frac{R}{28.65} \cdot \left[\cos^{-1} \left(\frac{R-D}{R} \right) \right] \quad (2)$$

Where, SSD_s = Available SSD for a given road geometry, m; R = Radius of the centerline of the HOV lane, m.; and D = Ordinate offset, m.

In highway facility design, the designer must provide sufficient ordinate offset so that the specified sight distance requirement, SSD_d is satisfied, that is:

$$SSD_s \geq SSD_d \quad (3)$$

For a single-lane HOV facility design, the minimum curve radius to satisfy Equation (3) can be back-calculated with any given facility design speeds and ordinate offsets.

For example, when the HOV lane width $w_{hov} = 3.66$ m, the outside shoulder width, or the buffer width, $w_o = 1.22$ m, the mixed flow lane width, $w_m = 3.66$ m, the typical vehicle width, $w_{veh} = 1.83$ m (A Toyota Camry sedan is about 1.77 m wide, and a Chevrolet Tahoe sport utility vehicle is 2.01 m wide), then $D = w_{hov} * I/2 + w_o + (w_m - w_{veh})/2 = 3.97$ m. Therefore $R_{min} = 1432$ m at a design speed of 110 km/h.

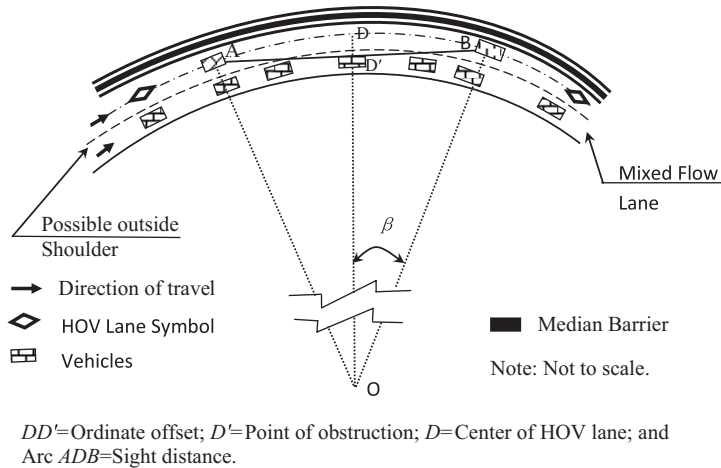


Figure 6. Sight constrained when the alignment curves to the right

3. RESULTS AND DISCUSSIONS

3.1 Results

A host of calculations was performed to determine the minimum horizontal curve radius necessary to provide the required stopping sight distance. Different combinations of design speeds, shoulder width, outside buffer width, and mixed-flow lane width were used in the calculations. The relationships between the minimum curve radius and the left shoulder width (when curves to the left) or right buffer width (when curves to the right) were plotted and shown in Figure 7 and Figure 8.

As a retrofitted facility, the single-lane HOV facility typically incorporates some non-standard features, such as non-standard left shoulder width, HOV lane width, adjacent mixed-flow lane width, and right shoulder width (if any), and right buffer width (if any). The inside shoulder width and outside buffer width may be as narrow as 0.0 m. The HOV and mixed-flow lane width may be as narrow as 3.35 m. These non-standard features may significantly reduce the available sight distance and therefore are also included in the calculations. For example, in Figure 7 the HOV lane width is 3.66 m; while in Figure 8, the HOV lane is 3.35 m, which is considered as the minimum acceptable lane width in practice.

As shown in Figure 7, the two lines on top represent a higher design speed of 110 kph; while the other two lines represent a lower design speed of 80 kph. It is apparent,

because a higher design speed calls for larger minimum radius. For the top two lines, the upper one represents the minimum radius required when the facility curves to the left; while the lower one represents the minimum radius required when the facility curves to the right. This means that the left shoulder width governs the design, given equal left shoulder width and right buffer width. However, when the left shoulder width becomes larger than 0.92 m, the right buffer width may control the design. The 0.92 m is half of the adjacent mixed flow lane width less a standard vehicle width (1.83 m as mentioned before).

For example, when the left shoulder width is 1.22 m, the required minimum curve radius is 1863 m when design speed is 110 kph. At the same time, if the right buffer shoulder width is zero (HOV lane is contiguous with the mixed-flow lanes), then the minimum required curve radius is 2069(>1863) m. This will be a serious oversight if the obstruction from congested traffic in the adjacent lane is not taken into consideration. At a lower design speed, say 80 kph, the same observation holds as shown by the two lower lines in Figure 7.

The situation worsens if the HOV lane width is decreased to 3.35 m as shown in Figure 8. At this time, the minimum left-turn curve radius required is 1960 m when the design speed is 110 kph and left shoulder width is 1.22 m. However, the minimum right-turn curve radius is 2191 (>1960) m when the HOV lane is contiguous with adjacent mixed-flow lanes.

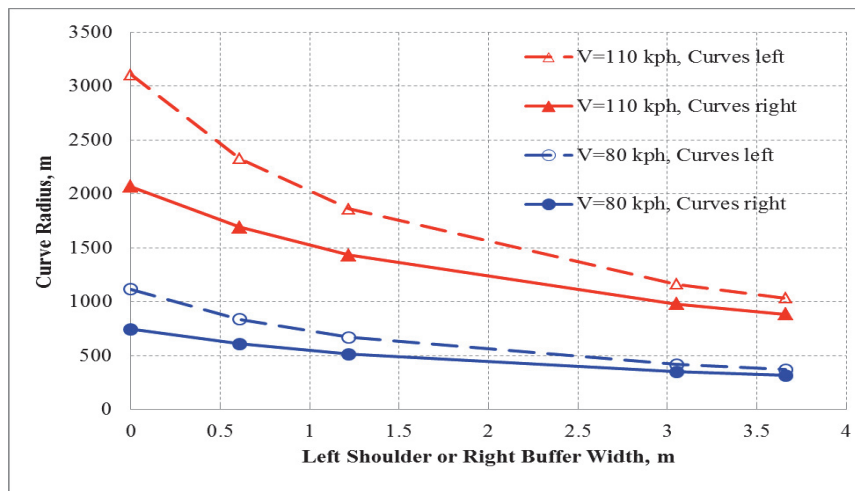


Figure 7. The minimum horizontal curve radius when SSD is met (HOV lane width = 3.66 m, mixed-flow lane width=3.66 m, and $t=2.5$ s)

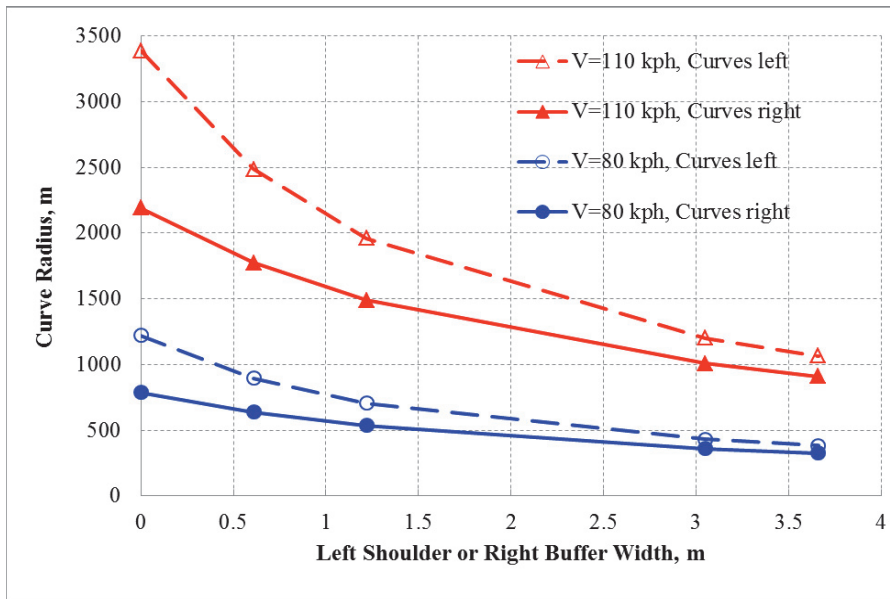


Figure 8. The minimum horizontal curve radius when SSD is met (HOV lane width = 3.5 m, mixed-flow lane width=3.66 m, and $t=2.5$ s)

3.2 Potential Countermeasures

Several measures can be taken to help satisfy the required stopping sight distance for the single-lane HOV facility users. Geometric improvement would be the most desirable. Increasing horizontal curve radius, increasing left and right shoulder width for the single-lane facility would help. Most importantly, use sufficient buffer width on the right-hand-side at a tight horizontal curve. This will help prevent queued vehicles from blocking a HOV lane driver's line of sight. The minimum curve radius can be read out from Figure 7 and 8.

Since sight distance is closely related to the HOV lane's operating speed and driver behavior, obviously limiting the HOV lane operating speed will be an effective countermeasure. As Figure 7 and 8 show, the minimum horizontal curve radius required when the design speed is 80 kph is about one-third of that when the design speed is 110 kph.

4. CONCLUSIONS

An effort was made to demonstrate the horizontal sight distance issues for a single-lane HOV facility retrofitted along the median of an existing freeway. The minimum horizontal curve radii required to satisfy the stopping sight distance at different design speeds were determined, based on different combinations of inside shoulder width, outside buffer width, HOV lane width, and mixed flow lane width. As a single-lane

facility, the minimum curve radius is influenced in the same way by both the inside shoulder and outside buffer width. It was found that for a contiguous HOV lane, the congested traffic in the adjacent mixed-flow lane will govern the design, as long as the left shoulder width is more than 0.92 m. It is therefore equally necessary to check for sight distance impairment as a result of queued traffic in the adjacent mixed-flow lanes when the alignment curves to the right.

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